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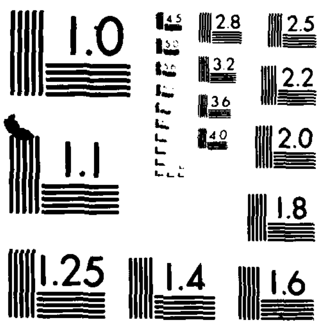

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DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

AERONAUTICAL RESEARCH LABORATORIES

MELBOURNE, VICTORIA

Aerodynamics Technical Memorandum 326

A PROPOSAL FOR AN AUSTRALIAN HYDRODYNAMICS LABORATORY

N. MATHESON and D.C. COLLIS

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SUMMARY

To support and stimulate both naval and commercial ship design and construction there is a requirement, judged to be of sufficient magnitude and of a continuing nature, for a hydrodynamics research and testing facility in Australia. This report contains details of the requirements for the facility, the form it may take, and the type of equipment that would be needed to meet Australia's perceived needs in hydrodynamics research and development. The capital cost of the laboratory is estimated to be \$27M spread over nine years, with running costs of \$2M per annum.

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16. ABSTRACT:

To support and stimulate both naval and commercial ship design and construction there is a requirement, judged to be of sufficient magnitude and of a continuing nature, for a hydrodynamics research and testing facility in Australia. This report contains details of the requirements for the facility, the form it may take, and the type of equipment that would be needed to meet Australia's perceived needs in hydrodynamics research and development. The capital cost of the laboratory is estimated to be \$27M spread over nine years, with running costs of \$2M per annum.

CONTENTS

1. *INTRODUCTION*

The concept of establishing a Hydrodynamics Laboratory in Australia for ship model testing, development, and research was proposed early in 1970 and examined by an interdepartmental committee in 1971, but no further action was taken, even though the proposal was supported by the then Departments of the Navy, Defence, Supply, Shipping and Transport, and Education and Science.

Recently, the Australian Science and Technology Council recommended that long term plans for upgrading and extending research and development facilities in Aeronautics and Aerospace be drawn up by the Department of Defence in co-operation with other interested parties. Naturally, this type of study has to include relevant fields in addition to aerodynamics, for example, propulsion, structures, materials and possibly hydrodynamics. Since aerodynamics and hydrodynamics have much in common, and because facilities in one can be used to supplement those in the other, it seems appropriate, at this time, to re-examine the need for a hydrodynamics Laboratory, and if there is a significant requirement, to indicate the types of facilities that would be needed and the costs involved. A previous proposal by Collis[1] in 1970 forms the basis for this re-assessment.

Hydrodynamic testing facilities and techniques have been developed to the stage where most aspects of the performance and behaviour of ships (and other marine vehicles) can be predicted reliably using scale models. Nowadays, because costs are so high, new designs are always subjected to comprehensive model tests before a ship is built. This usually indicates that changes are needed to improve the performance or seakeeping and manoeuvring qualities. But, when design modifications are made to improve these characteristics, changes in other parameters already established often occur, and the iterative design procedure is continued until the best compromise between all of the requirements is achieved. This prevents costly mistakes from being made, and obviously enables the most effective hull to be developed more easily and at much lower cost than by resorting to full size prototypes.

Recent trends, for example toward large displacement and high speed cargo ships, very high speed naval vessels, and stable offshore oil drilling platforms, have reinforced the necessity of hydrodynamic model testing by raising problems in propulsion, stability, and seaworthiness, that can only be solved through intensive research and development. The economic penalty for failing to achieve the best design, within given constraints, or for failing to attain design performance, are currently so great that they make model testing an essential part of the design process. The importance of this type of facility is indicated by a continued increase in world wide usage, coupled with the construction of new model basins and the upgrading of existing ones[2,3,4,5].

2. REQUIREMENT FOR AN AUSTRALIAN HYDRODYNAMICS RESEARCH AND DEVELOPMENT LABORATORY

Even though there has been a downturn in requirements for the design and construction of large ships in Australia, corresponding to recent world trends, there has been an increase in demand for a wide variety of craft up to around 10,000 tons gross for both defence and civil needs. To meet this requirement there is an active commitment to ship design by the Royal Australian Navy and by the Shipbuilding Division of the Department of Industry and Commerce, and construction is carried out in 14 yards throughout Australia[6]. To support and stimulate both Naval and Commercial ship design and construction there is a requirement, judged to be of a continuing nature, for a hydrodynamics research and testing facility. This would assist naval architects to design ships to meet stipulated performance criteria economically and safely. Because of the existing lack of facilities, ship model tests have to be carried out overseas, usually in the United Kingdom, but sometimes in The Netherlands, Germany or Sweden.

The average budget for development testing of a single ship design is mostly less than 0.1% of the total value of one vessel, and this includes "research" sponsored by the design authorities. This is an exceptionally small sum given that from 1 to 3 ships (or more for naval craft) of a particular design are usually built, especially when compared with the aircraft industry where R&D expenditure can be 10 to 30% of the total cost of a large production run. The hydrodynamics facility may also be compared with the support given to the aircraft industry (particularly the RAAF), where the Aeronautical Research Laboratories, currently maintained at an annual cost of around $10M, have assisted in the design and development of local aircraft, but are now more concerned with supporting military aircraft operations. A much greater investment in hydrodynamics is considered necessary if Australia is to maintain a capability in ship design in an era of rapidly increasing technological complexity in the industry.

It is assumed that the facilities would be available to all interested parties. Other users may include Defence establishments for the development of missiles and torpedoes, air authorities for miscellaneous work such as ditching trials, and Universities for research and education. The complementary nature of hydro- and aerodynamic test facilities is shown by tests made recently on a 2 m wingspan model of a Boeing 747 aircraft[7]. This was tested in a towing tank to determine the effect of wing trailing vortices on following aircraft. In this case, a towing tank is preferred to a wind tunnel so that the wake can be studied at great distances downstream of the aircraft.

Later in this report, details are given of a range of facilities considered appropriate to meet Australia's perceived needs in hydrodynamics research and development. The broad arguments leading to these proposals are as follows:

1. There is a current and continuing need for expertise over a wide area of hydrodynamics to satisfy the technical requirements in designing and developing the diverse range and type of naval and merchant vessels necessary for Australian operation. These include investigations by the Navy of designs for patrol boats, combat support and replenishment ships, destroyers, and frigates, together with modifications and refits to existing ships. In addition, forward design studies, necessary for an effective Navy, are critically important and include examinations of new concepts in hull forms and propulsion systems. In the civil field, vessels range from motor launches and yachts, through tugs to freighters, bulk carriers and tankers up to about 80,000 tonne displacement. As well as ships, there is a requirement for the development and testing of underwater rockets, missiles, and torpedoes for defence purposes.

2. Existing local experimental facilities (discussed in section 4) are not adequate for ship design and development, and there is some restriction on their availability as well as a lack of suitably qualified and experienced staff.

3. Australia, as an island continent, has a critically high requirement to maintain competence in ship design, especially for naval purposes, so that its maritime strength can be maintained and readily increased, especially in times of national emergency. The cost of not having a local facility to meet these requirements is virtually impossible to estimate. The use of high technology high speed craft for coastal operations is becoming a very important Defence requirement.

4. Local conditions of usage or geography often require specialized hulls which could be better designed in Australia. For example, there is a need to operate fast ships of large carrying capacity through the shallow waters to Torres Strait. This tends to dictate the use of full after-body lines, which in turn raises the possibility of problems in propulsion and manoeuvring. Since knowledge in these fields is lacking, the designer is forced to be conservative, possibly at the expense of efficiency and performance. Local facilities would allow supporting research suitable for local needs.

5. It is impossible to appreciate the subtleties of current overseas research results without a vigorous local research effort. This deficiency must induce conservatism, if not stagnation and obsolescence, in local design, and lead to higher capital, operational and maintenance costs, as well

as the possibility of severe service problems such as cavitation, vibration, noise, and poor handling. Research contributions would also facilitate the exchange of up-to-date information with other countries, some of which may otherwise be restricted, give the opportunity to explore problems as they arise, and add to the general scientific base in hydrodynamics.

6. The use of overseas facilities introduces particular difficulties in the following areas:

6.1 Unacceptable delays caused by the scheduling being done to suit the testing authority. If initial tests indicate that the design is deficient and changes are needed, then re-scheduling at the end of the queue is usual, resulting in even greater and often unacceptable delays, or curtailment of the iterative design process and a less than optimum ship.

6.2 Constraints on lines of investigation can occur, because the testing authority only carried out the tests specified, so that the most effective hull need not be forthcoming. An Australian facility would allow local control of test schedules and provide flexibility in pursuing the optimum design.

6.3 Security of designs for Defence purposes would be maximized using a local facility.

6.4 Communication difficulties between the designer and testing authority can lead to complications, especially if unfavourable characteristics are detected. Face-to-face contact offers the best prospect for planning tests, resolving technical problems, and in interpreting and assessing test results. It also allows the designer to appreciate various aspects of design and scaling, and to develop confidence in test procedures and results. Sometimes important information may even be lost because it has been pre-judged by overseas authorities to be irrelevant.

6.5 Test procedures and sea-state conditions tend to be standardized to suit normal requirements of the testing authority. These are not necessarily those most appropriate for Australian conditions or the seas in which the ship will usually operate[8]. This is important in ensuring structural integrity and efficiency. Without local experience it is hard to determine whether the test procedures and sea-states are the most appropriate, and it is difficult to specify alternate ones. An Australian facility would ensure that test conditions were matched to local needs.

Overall, an Australian Hydrodynamics Laboratory would be of great value and very effective in building up competence in hydrodynamics. More specifically, it would be of benefit to both Defence and Industry for examining specific proposals quickly at the initial design stage, and later for testing of modifications to the most promising design, investigating and correcting problems in service, carrying out research aimed at local needs, and for contributing to education and training.

The lead time to build the experimental facilities and develop skill in their use is long - in the vicinity of 5 to 10 years[9]. It is therefore necessary to act now to provide for a local independent capability in hydrodynamics for the future, particularly in the evolution of Australian ship design and construction. This is especially important for meeting Naval requirements which are perceived to extend beyond conventional surface ships to hydrofoils, surface effect ships, semi-submersibles, submarines, torpedoes, and sea-to-air rockets. Already difficulties have been encountered in systems evaluation of some equipment because hydrodynamic data are lacking. Therefore, in this respect, even current needs are not being met.

3. RESEARCH AND DEVELOPMENT ACTIVITIES OF THE HYDRODYNAMICS FACILITY

It is envisaged that the facility will enable hydrodynamic research and development to be carried out to meet the needs of designers, builders and operators of marine vehicles including surface ships, semi-submersibles, hydrofoils, hovercraft, submarines, torpedoes, and advanced concepts such as semi-displacement foil ships, in both naval and commercial spheres. More specifically, it will enable these craft to be studied in detail so that their design and performance can be optimized or their feasibility ascertained. In addition, it will allow work for other countries to be undertaken, as part of an offset agreement against defence (or industry) purchases, or on a commercial basis.

Four broad areas of activity are seen to be necessary to meet the above requirements. They are discussed in the following, and the experimental facilities required for effective engagement in these activities are described in section 5.

3.1 Hydrodynamic Design and Testing of Marine Vehicles and Components

This is a direct service to meet the immediate needs of industry and public authorities such as the Navy. Work would include hull and propeller design, combined with tests to determine the resistance, propulsion, manoeuvrability, and sea-keeping characteristics of new ships.

A typical test programme would involve observations and measurements on a model hull, both with and without a propeller, in a towing tank, seakeeping basin, and either a circulating water channel or water tunnel (usually propeller only), and the issue of reports including recommendations for modifications to improve the efficiency and other characteristics of the vessel. Follow-up action may involve retesting and/or more detailed studies of the flow around the hull, propeller or rudder, depending on the initial findings.

Work in this category would also include studies of control and stabilizing devices such as bow thrusters, rudders, skegs, and keels, and miscellaneous investigations for harbour and Marine authorities and the like. For example, work may involve studies of the effects of waves on harbour installations, or the circumstances which have led to collisions or near misses between vessels or other objects. Training of ship operators in manoeuvring and seakeeping may also be included.

3.2 Applied Research

One of the tasks envisaged here is the collection, codification and assimilation of the often scattered results of research on topics related to ship design. Currently, detailed design information on ship hydrodynamics available to Naval Architects in "handbook" form still appears to be rather limited, possibly because the subject has remained empirical in nature and different approaches are adopted by different establishments. But efforts are being made to overcome, this. For example, the British Ship Research Association and the Royal Institution of Naval Architects in England, and the Society of Naval Architects and Marine Engineers in America have accumulated much information in the field, and this is available on request. In comparison, the aeronautical design engineer, is well catered for by publications such as the Aerodynamics Data Sheets put out by the Engineering Science Data Unit in Great Britain, and the comprehensive series of the United States Air Force known as Stability and Control DATCOM.

Other areas of applied research would include:

1. Solving particular problems occurring in operation but where little information is available.

2. Pin-pointing areas where basic research is urgently needed.

3. Evaluation and development of new concepts, for example, new hull shapes, new propulsion devices, new stabilizing and maneuvering aids, and new types of underwater missiles.

4. Operation of aircraft from ships.

5. Noise suppression to reduce the likelihood of detection.

6. Water exit and entry of missiles, and impact landing of objects, such as aircraft during ditching, seaplanes, and other bodies.

3.3 Basic Research

Here, the object is to establish principles and quantitative relationships in hydrodynamics which are relevant to ships in particular, and to put forward new ideas and design concepts leading to improved performance. An example of this type of work would be the study of the flow over ships hulls, both "rough" and "smooth" which must be well understood for efficient hull design, propulsion, and control. Another area is the reduction of friction by injecting dilute polymer solutions into the boundary layer of the hull so that it effectively operates in a non-newtonian fluid.

3.4 Research and Development of Testing Techniques

This activity falls into two distinct categories.

1. Research relating to the introduction, continuous updating, and improvement of instrumentation and data acquisition and processing systems.

2. The evaluation and improvement of existing test procedures and the development of new ones. This is necessary because it is important to make model tests under the most realistic conditions possible. Apart from the practical difficulties involved in precisely reproducing the geometry of the hull and propeller, and the dynamic characteristics of the propulsion system, there is a fundamental problem caused because the Froude number and Reynolds number scaling requirements cannot be satisfied simultaneously. The prediction of full scale performance from model results is therefore of perennial importance.

   Two other examples in this area have been raised locally. One is the question of whether the standard procedure used by an overseas testing authority in maneuvering trials is a valid one in all situations. The other is that of specifying sea-states for design purposes and hence for model tests, which are relevant to ships plying Australasian waters.

4. EXISTING HYDRODYNAMICS FACILITIES

Australia has no central laboratory for hydrodynamics research and development. Although there are some small experimental facilities located in Universities and Colleges, they are too small for reliable commercial use, and the majority of tests have to be made overseas, as mentioned earlier.

To the Authors' knowledge, there have not been any significant new items of equipment commissioned in Australia in the last decade. Brief details of existing facilities are given in table 1.

TABLE 1. Existing hydrodynamic facilities in Australia

Location	Type of Equipment	Working Section Dimensions	Maximum Test Speed (m/s)	Power (kW)
University of Melbourne	Towing tank	61 m long 1.8 m wide 2.1 m deep	3.1	
	Water channel, slotted wall	3.1 m long 0.61 m wide 0.41 m deep	1.2	
University of Sydney	Towing tank	57 m long 2.7 m wide 1.6 m deep	5.0	
	Water channel, slotted walls	0.84 m wide 0.41 m deep	1.1	
	Water/wind tunnel (either open or closed with air, closed only with water)	0.91 m wide 0.61 m high 1.8 m long	6.0 water 30.0 air	110
University of Adelaide	Water tunnel, closed jet	2.4 m long 0.46 m diameter	9.1	190
	Towing tank	34 m long 1.2 m wide 0.9 m deep		
University of Queensland	Water tunnel, closed jet	1.7 m long 0.34 m diameter	6.7	37
Australian Atomic Energy Commission	Water tunnel, closed jet	1.05 m long 0.22 m diameter, or, 0.15 m x 0.30 m	6.0	75
Aeronautical Research Laboratories	Water tunnel, closed jet	0.75 m long 0.25 m x 0.25 m	1.0	5

Apart from student training, the equipment is used mainly for research by staff and postgraduate students. A little development work is also undertaken for outside agencies; for example 12 m yacht designs have been investigated in both towing tanks, a variety of flow measuring instruments have been calibrated at Melbourne, and studies of propeller performance and vibration, and the flow about bodies have been undertaken in the water tunnels.

The two main towing tanks are very small by international standards, but are suitable for their intended purposes of meeting student requirements, instrument calibration, and 'small scale' hydraulics experiments mostly not directly related to ships. However, some research on ships is feasible in small tanks, for example extensive 'small-boat' research has been carried out in a 95 m long x 3.7 m wide x 1.8 m deep tank at Stevens Institute of Technology in USA. Acceptable model sizes range up to 3 m in length for the Sydney tank and 2.5 m for the Melbourne tank, although smaller models may have to be used depending on hull shape and the interference effects that can be tolerated.

The water tunnels are all of the closed loop, closed jet type, and are relatively larger than the towing tanks by world standards, and allow more realistic test conditions. For example, a limited range of tests can be carried out on some propellers up to about 0.25 m in diameter. On the other hand, the water channels are too small for reliable ship development testing.

5. PROPOSED NEW HYDRODYNAMICS EXPERIMENTAL FACILITIES

Towing tanks, developed from the 85 m long tank used by Wm. Froude in 1871, have become the mainstay of ship research and development, and have been constructed in many countries both large and small. Currently, tank sizes range from less than 30 m long for student use, to a giant kilometre long tank in America. More recently, the need to study other phenomena, such as seakeeping and manoeuvring in waves, and propeller performance under varying conditions of cavitation, has led to the use of manoeuvring basins, closed circuit water tunnels, and other supporting experimental facilities. Diversification of equipment to meet special requirements has continued, so that a typical hydrodynamics research complex now comprises one or more towing tanks; a seakeeping and manoeuvring basin fitted with wavemakers and beaches (and sometimes a "rotating arm"); closed circuit water tunnels, open channels or flumes, and other special equipment for investigating phenomena such as hydroelastic impact and flow induced vibration.

Initially, five major items of test equipment are considered necessary for a viable hydrodynamics laboratory in Australia; two towing tanks, a seakeeping and manoeuvring basin, a water tunnel, and a free-surface water channel. This would be the minimum needed for the programme of research and development in section 3; in fact, all of the equipment would be utilized in developing a new ship design which would most likely be one of the first major commitments. Other items, such as a shallow water tank, a deep tank (for testing stability of ocean platforms), or a depressurized towing tank[10,11,12,13], could be added later if necessary. Naturally, scientific, technical, and administrative staff, complete with offices, workshops, model shops, and data processing equipment would be needed to run and support the facility.

Brief specifications of each of the five items of equipment, together with some considerations leading to their choice, are given in the next sections. Some compromise has been made between cost and size of the equipment specified. The dimensions and performance figures are necessarily somewhat arbitrary and may need slight modification to accommodate standard items or vary cost. Details of instrumentation and other items for each facility, while very important, are not considered in this report.

5.1 Towing Tanks

Tank dimensions and towing speed, which depend on model size, are the most important specifications. Brief details of many of the world's towing tanks are given in Appendix 1.

Large models are preferred for development testing to allow accurate representation of hull and propeller geometry, increase accuracy of measured data, and minimize scale effect and extrapolation errors. Model sizes of around 7 to 9 m have proved very successful in many overseas tanks. But costs of both model and tank increase rapidly with size, as do the time scales associated with some operations, particularly the handling and modification of models, and the design and construction of the tank.

Cross-sectional area of a tank is governed by the size and speed of the largest model to be tested. In the usual model speed range, wall-interference is mostly within acceptable limits of experimental accuracy provided the maximum submerged cross section of the model does not exceed about 0.4% of the water-filled tank section[9]. Optimum depth is about half (or slightly greater) of the width[9,14]. This leads to model sizes ranging from about $0.5\,w < L_m < 0.75\,w$, where w is width of tank, and L_m is length of model[9,14]. The cross sections of twelve tanks are shown in figure 1[15].

Tank length is the sum of the distances required for acceleration, test-run, deceleration and emergency braking, plus the length of towing carriage. Clearly the length depends strongly on the maximum towing speed which is governed by Froude's law of gravitational wave similarity. Viscous forces obey Reynolds law and cannot be scaled correctly at the same time as gravitational forces. However, some models (submarines) may only be subject to viscous forces, and in this case, the towing speed should be as high as possible.

The current proposal is for two tanks; the larger to serve the needs of ship design development and model testing, and the smaller for research and training.

5.1.1 Research towing tank

Proposed tank:

Dimensions: 75 m long (capable of extension) 4 m wide, 2 m deep

Maximum carriage speed: 8 m/s

Peak carriage driving power: 20 kW

Models: up to 3.5 m long

Auxiliaries: wavemaker; beaches; instrumentation; data recording, processing and display equipment (so that processed data are available in the laboratory for "engineering" study immediately after each test), and air conditioners.

Principal uses:

1. Basic hydrodynamic research.
2. Development of experimental techniques, studies of methods for correlating model results with full scale, and training of staff.
3. Resistance and propulsion tests on small models of ships in smooth and rough seas.
4. Component testing; for example, hydrofoils, high speed craft, rudders, and stabilizers.

5.1.2 Ship development towing tank

Proposed tank:

Dimensions: 200 m long (capable of extension) 10 m wide, 5 m deep

Maximum carriage speed: 15 m/s (capable of upgrading to higher speed)

Peak carriage driving power: 700 kW

Continuous carriage driving power: 400 kW

Models: up to 8 m long and 2 tonne weight

Auxiliaries: wavemaker; beaches; instrumentation; data recording, processing and display equipment; automatic sequence control to operate carriage, measuring recording and processing equipment; and air conditioners.

Principal uses:

1. Resistance and propulsion testing of models of a wide spectrum of ships of all sizes, including, submersibles. semisubmersibles, surface effect ships and unconventional vehicles, in smooth water and regular waves (head or stern only).
2. Measurement of any combination of forces and moments on waterborne or submerged bodies. Unsteady forces and moments, and vibration studies may also be included with suitable instrumentation.
3. Pressure and velocity distribution measurements on and around hulls and fully submerged bodies, propeller blades, and appendages such as ducts and shafts.
4. Flow visualization studies.
5. Free running model tests in head and following seas.

The capabilities of this tank are similar to those of tanks in Holland, Norway, Sweden and Yugoslavia, but are somewhat inferior to those in France, Italy, Japan, Spain and USSR, as can be seen from Appendix 1. Very much larger tanks exist in UK and USA.

5.2 Seakeeping and Manoeuvring Basin

A seakeeping basin provides a large expanse of water for simulating sea-going conditions and manoeuvre tests where there are large deviations from a straight course. The water surface may be disturbed by regular waves, as in ocean swells, or the sea may be confused due to combinations of waves of different height and length brought about by varying winds. Some of the better known seakeeping basins are listed in Appendix 2.

Proposed basin:

Dimensions: 30 m long, 30 m wide, 2.5 m deep

Auxiliaries: wavemakers on two adjacent sides, beaches on remaining sides, overhead observation platform, model tracking equipment and appropriate instrumentation, data recording, processing and display equipment.

Principal uses:

1. Determination of directional stability, control, and manoeuvring characteristics in smooth and rough seas on free running surface models, submarines, and torpedoes.
2. Seakeeping tests in waves, and head, stern and cross seas.

This tank would not be large by world standards, and models up to about 3.5 m long could be tested.

5.3 Water Tunnel

In an open tank the air pressure on a model is too high compared with a full size hull. This does not detract from the general usefulness of open tanks, but cavitation studies, and some tests on propellers and hydrofoils, for example, require independent pressure variation. These studies are often made in a water tunnel where pressure is easily varied independently of flow velocity, although recently rather costly depressurized towing tanks have been used for more specialized studies of propeller-hull cavitation where free surface effects are present[11]. The list of water tunnels in Appendix 3 gives an indication of the world-wide usage of this type of facility. The layout of the Admiralty Research Laboratories '30-inch water tunnel' is shown in figure 2[16].

Proposed tunnel:

Type: closed loop, closed jet with either solid or slotted walls.

Layout: circuit arranged in vertical plane, with working section in upper horizontal limb.

Dimensions of working section: 0.60 m diameter, 2.0 m long (provision for alternative two dimensional working section).

Maximum water speed in test section: 9 m/s.

Total power requirement: 250 kW.

Models: axially symmetric bodies, approximately 1/6 of working section diameter for closed working sections[17], and 1/3 of working section diameter for slotted wall sections[16];
propellers, approximately 0.5 of section diameter for closed sections, and 0.7 of section diameter for slotted wall sections.

Ancillary equipment:

1. Controlled variation of total air content (deaerator).
2. Resorber to redesolve any air bubbles formed during testing.
3. Pressure control between 0.2 and 3 atmospheres.
4. Controlled variation of water temperature (cooling system to extract heat input from pump, and heating system to raise temperature - increase from 5° to 50° provides a three fold increase in Reynolds number).
5. Flow regulation, (using van Lammeren type check valves), to vary velocity across the working section.

6. Drain down tanks.
7. Water treatment and filtration plant to inhibit organic growth and corrosion, and remove impurities.
8. Instrumentation and data processing - similar to towing tanks.

Principal uses:

1. Marine propeller research, including partly and fully cavitating propellers, propeller vibration and singing, ducted propellers, and propeller performance in non uniform velocity fields.
2. Cavitation studies - including inception, life in a cavitation - erosion environment. Performance of propellers, turbines, pumps, hydrofoils, and other submerged bodies such as ship appendages, sonar domes and torpedo noses.

5.4 Water Channel

A recirculating water channel is needed for the study of flow around hulls and other similar bodies at or near a free surface, particularly when cavitation may be involved. In a channel, water is confined by solid or slotted boundaries at the bottom and sides and an air-water interface exists at the top. Since there is a free surface, modelling is governed by both Froude and Reynolds numbers.

Compared with a towing tank, a channel has the advantages of: continuous running, easier detailed flow studies, no restriction on placing instruments inside the model, and pressure variation above the water surface for cavitation simulation. But the test results are not as accurate as in a towing tank because smaller models must be used and because the flow is not as uniform.

Proposed channel:

Type: recirculating, with following working section options:

1. Free surface, either slotted[18] or solid walls.
2. Closed with airspace above water which can be depressurized, either slotted or solid walls.
3. Closed section, either slotted or solid walls.

Layout: circuit arranged in vertical plane, with working section in upper horizontal limb.

Dimensions of working section (water): 1.5 m wide, 0.9 m maximum water depth, 4 m long.

Maximum water speed in test section: 6 m/s

Total power requirement: 100 kW

Auxiliary equipment: deaerator, resorber, pressure control between 0.1 and 2 atmospheres, temperature control, water treatment plant, and instrumentation similar to water tunnel.

Principal uses:

research and development tests involving detailed studies of flow fields around a wide range of types of hulls complete with propellers, control surfaces and other appendages, at or near a free surface.

Note: Water channels and water tunnels are available commercially. For example, Kempf and Remmers in Germany have supplied this type of equipment to Institutions and Universities in many countries. For a new laboratory, they have the advantages of being complete and proven designs available at fixed prices. Slight modification to specifications for the tunnel and channel would be acceptable to obtain standard commercial items.

6. ESTIMATED COSTS AND PHASING OF EXPENDITURE

6.1 Cost Estimates

The estimated cost of major items initially required for the Hydrodynamics Laboratory, given in table 2, must be regarded as approximate because they relate to specifications which are still imprecise. However, they are based on local experience with the development of aeronautical research facilities of a broadly similar character, and are consistent with the very few figures readily available from overseas[9,19,20].

TABLE 2. Estimated costs of major items for the Hydrodynamics Laboratory

	Item	$M
1.	Research towing tank	1.5
2.	Ship development towing tank	7.0
3.	Seakeeping and manoeuvring basin	2.5
4.	Circulating water channel	1.2
5.	Water tunnel	1.2
6.	Instrumentation, data acquisition and processing equipment	2.5
7.	Model making and general workshop equipment	2.0
8.	Civil engineering on site	0.3
9.	Buildings and offices	3.5
10.	Engineering design	2.5
11.	Contingencies	2.8
	Total	27.0

The cost of acquiring a site is not included in the estimates.

6.2 Phasing of Expenditure

An indication of how the construction activities and phasing of expenditure is envisaged is given in table 3.

TABLE 3. Phasing of expenditure

Year	Activity	Expenditure $M
1.	Overall planning, design and specification of facilities (except development towing tank), site engineering.	0.8
2.	Design (continued), site engineering, letting of contracts for research towing tank, water tunnel, and seakeeping basin.	2.7
3.	Construction of buildings, research towing tank, seakeeping basin, channel and water tunnel. Design of development towing tank.	6.0
4.	Erection of channel and water tunnel, outfitting workshops, procurement of instrumentation. Complete design of development towing tank and let contracts.	5.5
5-6.	Construction of development towing tank.	6.0
6-9	Purchase instrumentation for development tank, and complete fitting out and instrumentation of other facilities.	3.2

7. SITE AND LOCATION

7.1 Requirements Governing Choice of Site

7.1.1 Physical

1. Site should be reasonably flat.
2. Ground must provide a suitable foundation, and be uniform in load bearing capacity.
3. Water table should be well below surface to allow deep excavation (if required) for towing and seakeeping tanks and avoid high foundation costs.

4. Area and dimensions must accommodate facilities proposed, and allow for possible future expansion. Trends towards higher speed vessels may lead to an extension of the development tank sometime in the future. Increased interest in performance in shallow water may also require the construction of a shallow water towing tank at a later date. The area required is approximately 4 hectares with a minimum length of 400 m.

5. Abundant and relatively pure water supply.

6. Site should be free from excessive noise and vibration.

7.1.2 Organizational

1. Location close to an existing shipbuilding yard would facilitate communication between builders and designers.

2. Location close to, and associated with, an institution having related research objectives, such as the DSTO Aeronautical Research Laboratories and/or engineering departments of the Universities of Sydney, New South Wales, or Melbourne, and certain divisions of the CSIRO, would provide intellectual stimulus and cross fertilization of ideas, as well as providing access to established collections of scientific literature.

3. Location close to an existing related Commonwealth engineering research and development establishment may help in the provision of engineering services.

4. Low speed wind tunnel facilities have become a necessary adjunct of a hydrodynamics laboratory, and location close to existing facilities of this nature would enable them to be used advantageously for:

   1. Investigating aerodynamic drag of ships.
   2. Studying hydrodynamic phenomena in the absence of waves, surface tension and cavitation.
   3. Investigating funnel effluent dispersal, wind screening and similar problems.

   Most of the institutions referred to previously have some low speed aerodynamic facilities, but the Aeronautical Research Laboratories are, naturally enough, outstanding in this respect.

5. Convenience of access for staff and clients, and a congenial environment are also very important considerations. For staff, these are a daily and continuing concern, but for individual clients, an occasional one. While the clients interests may influence the choice of a geographical site, the interests of staff should weigh more heavily in the precise location within the area selected.

8. MANAGEMENT AND STAFFING

The hydrodynamics laboratory is envisaged to start as a group specially set up within an existing laboratory such as ARL. Initially this group would concentrate on design aspects of the hydrodynamics laboratory in consultation with other Government Departments and Authorities, and intended users. As the facilities become available more staff would be taken on until the facilities are completed and the laboratory becomes fully operational.

Estimated staff requirements and a time scale for their engagement are shown in table 4 for three different phases of the project. The end-point of any phase would not be sharply defined and the staff build-up would be progressively adjusted to the work-load and availability of experimental facilities. The activities envisaged during the three phases are as follows:

Phase 1. planning, design, procurement and installation of facilities.

Phase 2. facilities completed, research programme initiated, model testing in progress.

Phase 3. enhanced level of ship model testing, consequent on demonstration of competence by testing authority and subsequent growth in demand from industry.

TABLE 4. Estimated staff for the hydrodynamics laboratory

Type of staff	Phase		
	1. 0-3 years	2. 3-6 years	3. 6+ years
Professional	9	22	28
Technical	10	12	17
Administrative	2	3	4
Trade	0	6	9
Totals	21	43	58
Annual salary costs $M	0.5	1.0	1.3

The staff estimates in table 4 are based on the assumption that the hydrodynamics laboratory is associated with a larger organization providing common services such as administration, library, and some engineering design, workshop, and maintenance facilities.

The staff figures in table 4 compare favourably with the Ship Division of N.P.L. This Division began operating in 1910, and by the late thirties staff totalled about 50, the main facilities then being two towing tanks somewhat similar to the two proposed here. In 1959, when larger more comprehensive facilities at Feltham came into use, the staff totalled 53, and the distribution between classifications was similar to that proposed in table 4. It should be noted, however, that there are several other ship hydrodynamics facilities, both publicly and privately owned, in the United Kingdom, (see Appendix 1) including the large and comprehensively equipped Admiralty Experiment Works at Haslar. Thus the total number of people engaged in hydrodynamics research and development is much greater than the 50 of N.P.L.

9. CONCLUDING REMARKS AND RECOMMENDATIONS

1. To support and stimulate both naval and commercial ship design and construction there is a requirement, judged to be of sufficient magnitude and of a continuing nature, for a hydrodynamics research and testing facility in Australia. This paper is a first step in a proposal for such a facility. It contains details of the requirements for the facility, the form it may take, and the type of equipment that would be needed to meet Australia's perceived needs in hydrodynamics research and development.

2. To enable the research and development activities of the laboratory to be carried out successfully, five major items of equipment are necessary and they are:

1. Ship development towing tank, 200 m long, 10 m wide, 5 m deep, with a carriage speed of 15 m/s.
2. Research towing tank, 75 m long, 4 m wide, 2 m deep, with a carriage speed of 8 m/s.
3. Seakeeping manoeuvring basin, 30 m long, 30 m wide, 2.5 deep.
4. Water tunnel, recirculating with closed jet and slotted walls, 0.6 m diameter, 2 m long working section, maximum water speed 9 m/s.
5. Water channel, recirculating with free surface, slotted or solid walls, capable of being depressurized in airspace above free surface. Working section 4 m long, 1.5 m wide, 0.9 m water depth, and a maximum water speed of 6 m/s.

3. The capital cost of the facility is estimated to be $27M spread over 9 years, and the running costs are estimated to be $2M per annum. This investment is a long term one since the facilities are likely to have a life span in excess of 40 years.

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APPENDIX 1. Towing tanks[2,3,5,15,21].

...E. Length of tank mostly includes docking area.

Name and location of towing tank	Date of estab.	Carriage maximum speed (m/s)	Water Length (m)	Water Breadth (m)	Water Depth (m)
...ENTINE					
...al De Experiencias De ...uitectura Naval, Universidad ... Buenos Aires.	1962	4.0	72.2	3.6	2.0
...TRALIA					
...iversity of Sydney, New South ...ales.	1953	5	57	2.7	1.6
...iversity of Melbourne, Victoria.	1967	3.1	61	1.8	2.1
...TRIA					
...iffbautechnische ...rsuchsanstalt, Wien.	1919	8.5	180	10	5
...RAZIL					
...stituto De Pesquisas ...echnologicas, Sao Paulo.	1958 1956	5.0 5.0	142 60	6.7 3.7	4.0 2.2
...LGARIA					
...lgarian Ship Hydrodynamics ...entre [2].	1974	6	200	16	6.5
...ANADA					
...tional Research Council, Maritime ...ynamics and Ship Laboratory, ...ttawa.	1942 1930	8	137 122	7.6 2.7	3.0 1.8
...ctuz Ship Hydrodynamics ...stitute, Ottawa [4].	1974	6	150	11	5.5
		Joined	at end to		
	1974	6	70	11	1.3
... Research, Ocean Engineering ...tre, Vancouver, British ...umbia [20].	1975 1975	9 9	67 67	3.6 4	2.4 0.8
...ILE					
...tro de Estudios de Construction ...a, Universidad Tecnica del ...ado, Valdivia.	1972	4	45	3	2

APPENDIX I (CONTINUED)

Name and location of towing tank	Date of estab.	Carriage maximum speed (m/s)	Water Length (m)	Water Breadth (m)	[illegible]
DENMARK					
Hydro- og Aerodynamisk Laboratorium, Lyngby	[illegible]	[illegible]	240	12	[illegible]
	[illegible]		19	2	[illegible]
	[illegible]		15	1	[illegible]
FINLAND					
Icebreaking Model Basin. Wartsila, Helsinki Shipyard, Helsinki	1970	[illegible] (illegible)	51	4.8	[illegible]
Helsinki University of Technology, Ship Hydrodynamics Laboratory, Otaniemi [24].	[illegible]	[illegible]	1[illegible]8	11	[illegible]
The School of Technology of Turku, Ship Laboratory, Turku.	1979	[illegible]	39	1.9	[illegible]
FRANCE					
Bassin D'Essais Des Carenes, Paris.	1906	5.5	160	9.8	[illegible]
	1935		30	7	[illegible]
	194[illegible]		20	[illegible].7	[illegible]
	1950	5	155	8	[illegible]
	1956	10	220	13	4
GERMANY EAST					
Schiffbauversuchsanstalt, Berlin, Potsdam.	[illegible]	8.0	280	9.0	4.[illegible]
Shipbuilding Laboratory of the University of Rostock, Rostock.	1957	3.7	51	4.7	[illegible]
GERMANY WEST					
Hamburgische Schiffbau, Versuchsanstalt, Hamburg.	1953	5.0	80	5	
	1953	5.0	80	4	0.[illegible]
	1957	8.5	300	18	[illegible]
	1971	1.9	30	6	1.[illegible]
Versuchsanstalt Fur Binnenschiffbau, Duisburg.	1954	5.5	190	9.8	[illegible]
	1954	2.1	135	3.0	[illegible]
Versuchsanstalt Fur Wasserbau und Schiffbau, Berlin 12, Gartenufer.	1902	20	250	8	4.[illegible]
	1958	4	120	8	1.[illegible]
	1960	1.5	15	1.0	1.[illegible]

Name and Location of towing tank	Date of estab.	Carriage maximum speed (m/s)	Water		
			Length (m)	Breadth (m)	Depth (m)
GERMANY WEST (CONTD.)					
Institute Fur Schiffbau, Hamburg.	1962	[illegible].8	34	2.1	1.[illegible]
Schiffbaulaboratorium Der Freien und Hansestadt, Hamburg.	1924	2.0	40	6.5	[illegible]
INDIA					
Central Water and Power Research Station, Khadakwasla, Poona.	1955	6	226	3.7	[illegible]
Indian Institute of Technology, Madras.	1970	5.5	48 (?)	3.2	[illegible]
Dept. of Naval Architecture, Indian Institute of Technology, Kharagpur.	1953	4	61	4.4	2.[illegible]
Institute of Engineering Research Poona 5, Orissa.	1964		250	10	6
ISRAEL					
Technion, Israel Institute of Technology, Haifa.	1960	3	50	2.7	1.[illegible]
ITALY					
Istituto Nazionale Per Studi Ed Esperienze Di Architettura Navale, Rome.	1929	10	275	12.5	6
Istit. Nazion. Studi Ed Esperienze Di Architettura Navale, Roma, Nuovo Centro.	1971 1971	15 10	470 221	13.6 9	[illegible] 4
Istituto Di Architettura Navale, Universita Di Trieste.	1966	3	50	3.1	1.[illegible]
Istituto Di Architettura Navale, Universita Di Genova.	1947	2.8	49	2.9	1.[illegible]
Istituto Architettura Navale, Universita Di Napoli.	1972	10	137	9.0	4.[illegible]

Name and location of towing tank	Date of estab.	Carriage maximum speed (m/s)	Water		
			Length (m)	Breadth (m)	[illegible]
JAPAN					
Akashi Ship Model Basin, Akashi, Hygo [23].	197[illegible]	5	220	13	[illegible]
Fishing Boat Labs., [illegible] Agency, K[illegible]hidoki, Tokyo.	195[illegible]	2.2	63	4	[illegible]
Ishikawajima - Harima Heavy Industries Co. Ltd., [illegible], Yokohama.	196[illegible] [illegible]	5 2	[illegible] [illegible]	10 2.5	5 1.6
Hiroshima Univ., [illegible] Hiroshima.	[illegible]	5	[illegible]	5	[illegible]
Kobe University of [illegible] Marine, Fukae, Kobe.	[illegible] [illegible]	4 [illegible]	70 [illegible]	[illegible] 1.9	[illegible] [illegible]
Kyushu Univers[illegible] Institute for [illegible], Tsuyazaki, Fukuoka.	[illegible] [illegible]	[illegible] 6	[illegible] [illegible]	[illegible].5 3	[illegible] [illegible]
Kyushu University, [illegible] Fukuoka.	[illegible] [illegible]	5 [illegible]	[illegible] [illegible]	[illegible].6 [illegible].4	[illegible](5) [illegible]
Matsue Technical High School, Matsue.	197[illegible]	[illegible]	[illegible]	3	2
Meguro Model Basin, [illegible] Research and Development Institute, Defence Agency, Meguro, Tokyo.	[illegible] [illegible] 195[illegible]	[illegible] [illegible] 20	255 103 347	12.5 [illegible].5 6	[illegible] [illegible] [illegible]
Nagasaki Technical Institute, Mitsubishi Heavy Industries, Nagasaki.	194[illegible] 1954 1972	10 Joined [illegible] end to 5 [illegible]	150 120 190	12.5 6.1 30	[illegible] [illegible].7 [illegible]
		(also used for manoeuvring)			
Osaka University, Suita, Osaka.	1970	5	100	7.8	4[illegible]
Shimonoseki - Chuo Technical High School, Shimonoseki.	1961	[illegible]	25	2.1	[illegible]
Shipbuilding Research Centre of Japan, Mejiro, Tokyo.	1927 1961	4 4	207 207	10 8	[illegible] [illegible]

TABLE 1 (CONTINUED)

Name and location of towing tank	Date of estab.	Carriage maximum speed (m/s)	Water Length (m)	Breadth (m)	[illegible]
JAPAN (CONTD.)					
Suzaki Technical High School, Suzaki, Kochi.	1964		35	2.1	
Ship Research Institute, Mitaka, Tokyo.	1950	2	50	5	[illegible]
	1965	15	400	15	
	1972	[illegible]	150	7.5	
University of Osaka Prefecture, Sakai, Osaka.	[illegible]	2.5	70	3	[illegible]
University of Tokyo, Hongo, Tokyo.	1937	4	59	3.5	[illegible]
	[illegible]	[illegible]	[illegible]	5	[illegible]
	1967	[illegible]	[illegible]	[illegible]	[illegible]
University of Tokyo, Institute of Industrial Science, Azabu, Tokyo.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Yokohama National University, Ooka - Machi, Yokohama.	[illegible]	2	5[illegible]	3.0	
Yokohama Yacht Co. Ltd., Tsurumi, Yokohama.	[illegible]	[illegible]	[illegible]	1.0	[illegible]
University of Osaka, Osaka.	[illegible]	6.0	85	7.5	[illegible]
KOREA					
Seoul National University, Seoul.	1969	1.3	[illegible]	[illegible].5	1
Ship Model Basin, Inha University, Inchon	[illegible]	2.5	70	5	
NETHERLANDS					
Netherlands Ship Model Basin, Wageningen [19].	19[illegible]	9.0	252	10.5	[illegible]
	1958	5	216	15.8	[illegible]
	1960	30	220	4.0	[illegible]
	1972	4	240	18.0	[illegible]
		(Depressurized	towing	tank)	
Shipbuilding Laboratory, University of Technology, Delft.	1963	8	150	4.3	[illegible]
	1971	2	80	2.8	[illegible]

Name and location of towing tank	Date of building	Carriage maximum speed (m/s)	Water: Length (m)	Water: Breadth (m)
NORWAY				
Norwegian [illegible] Department, University of Trondheim and [illegible] Institute of Norway, Trondheim.	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	2.5
POLAND				
Ship Research Institute [illegible] University [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Ship Hydrodynamics [illegible] Design and Research [illegible] Gdansk-Oliwa.	[illegible]	[illegible]	[illegible]	[illegible]
SPAIN				
[illegible] Madrid.	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] Madrid.	[illegible]	5	[illegible]	[illegible]
SWEDEN				
The Swedish State Shipbuilding Experimental Tank (SSPA), Gothenburg.	[illegible]	14	[illegible]	[illegible]
Ship Hydrodynamics Laboratory, Royal Institute of Technology, Stockholm.	[illegible]	[illegible]	[illegible]	[illegible]
Division of Ship Hydrodynamics, Chalmers University of Technology, Gothenburg.	[illegible]	[illegible]	91	[illegible]
TURKEY				
Turkish Shipbuilding Research Inst., Istanbul.	[illegible]	[illegible]	[illegible]	[illegible]
UNITED KINGDOM				
Vosper Thornycroft, [illegible] Tank, Isle of Wight.	[illegible]	5	[illegible]	9.1
Ship Division, National Physical Laboratory, Teddington.	1911	4.2	153	9.1
	1932	7.4	104	6.1
		Joined end to end		
	1932	7.4	300	6.0

APPENDIX 1 (CONTINUED)

Name and location of towing tank	Date of estab.	Carriage maximum speed (m/s)	Water		
			Length (m)	Breadth (m)	[illegible]
UNITED KINGDOM (CONTD.)					
Ship Division, National Physical Laboratory, Feltham [9].	1959	15.2	400	14.6	7.[illegible]
Admiralty Experiment Works, Haslar, Gosport, Hants [13].	1887 1932	8.1 12.2	164 271	6.1 12.2	2.7 5.5
Southampton College of Technology, Southampton.	1964	4.6	61	3.7	1.[illegible]
Naval Architecture Experiment Tank, Glasgow University, Glasgow.	196[illegible]	[illegible].4	76	4.6	2.4
Vickers Limited, Ship Model Experiment Tank, St. Albans.	1911	6.[illegible]	127	6.4	3.4
Vickers Limited, Ship Model Experiment Tank, Dumbarton.	1884	9.[illegible]	100	6.8	2.5
Experimental and Electronic Laboratories, British Hovercraft Co. Ltd., Osborne.	1946 1956 1972	13.1 6.1 15.2	188 76 197	2.4 3.7 4.6	1.[illegible] 1.7 1.7
Upper Clyde Shipbuilders Ltd., Clydebank Div., Clydebank, Dumbartonshire.	1903	5.6	122	6.1	3.1
Kings College, University of Newcastle, Newcastle.	1952	5.5	40	3.7	1.[illegible]
UNITED STATES OF AMERICA					
Hydronautics Inc., Maryland.	1968	9	128	7.4	[illegible]
Lockheed Missiles and Space Co., Ocean Lab. Towing Basin, San Diego, California.	1955	30.5	98	3.7	1.[illegible]
Lockheed Missiles and Space Co., Underwater Missile Facility, Sunnyvale, California.	1958	12.8	55	4.6	4.[illegible] (8.[illegible]
St. Anthony Falls Hydraulics Lab., University of Minnesota, Minneapolis, Minnesota.	1954	7.6	77	2.7	1.[illegible]

APPENDIX 1 (CONTINUED)

Name and location of towing tank	Date of estab.	Carriage maximum speed (m/s)	Water		
			Length (m)	Breadth (m)	De[illegible] (m)
UNITED STATES OF AMERICA (CONTD.)					
United States Naval Academy, Annapolis, Maryland.	1951	3	28	2	1.2
	1975	6	40	2.6	[illegible]
	1975	15	116	8.6	5.3
M.I.T. Ship Model Towing Tank, Cambridge, Mass.	1953	7.5	33	2.6	[illegible]
University of California, Berkely, California.	1954	3.0	61	2.4	[illegible]
Dept. of Naval Architecture, Ship Hydrodynamics Lab., University of Michigan, Ann Arbor, Michigan.	1905	6.2	110	6.7	[illegible]
Webb Institute of Naval Architecture, Glen Cove, New York.	1947	5	28	3.0	[illegible]
Davidson Laboratory, Stevens Institute of Technology, Hoboken, New Jersey.	1934	9.2	42	2.8	[illegible]
	1944	30	92	3.7	[illegible]
David Taylor Naval Ship Research and Development Centre, Carderock, Maryland.	1948	10	846	15.5	[illegible]
	1939	9	92	15.5	3.1
	1948	50	905	6.4	[illegible]
	1938	3	43	3.0	[illegible]
Iowa Institute of Hydraulic Research, University of Iowa, Iowa City, Iowa.	1958	9.1	91	3	[illegible]
Collins Marine Laboratory, Collins Radio Co., Cedar Rapids, Iowa.	1959	6.7	27	1.8	[illegible]
National Aeronautics and Space Administration, Langley Field, Virginia.	1937	24	854	7.3	[illegible]
	1942	27	527	5.5	[illegible]
	1956	61	670	2.4	[illegible]
Newport News Shipbuilding and Dry Dock Co., Newport News, Virginia.	1933		17	2.4	[illegible]

APPENDIX 1 (CONTINUED)

Name and location of towing tank	Date of estab.	Carriage maximum speed (m/s)	Water		
			Length (m)	Breadth (m)	Depth (m)
U.S.S.R.					
Kryloff Schipbuilding and Research Institute[11], Leningrad.		8	60	6	3.5
		(Depressurized towing tank)			
	1891	8	134	6.7	3.3
	1950		672	14.9	7.0
	1950		218	16.0	2.0
Shipbuilding Institute, Leningrad.	1940		70	5.5	3.0
Cagi, Moscow.	1930		200	12.0	6.5
CKB-51, Garkij.	1938		16	3	1
Institute of Water Transport, Odessa.	1932		34.5	6.0	2.2
YUGOSLAVIA					
Brodarski Institute, Zagreb.	1959	8	276	12.5	6.2
	1959	12	302	5.0	3.2
	1954	3	44	3.0	2.5

APPENDIX 2. Seakeeping and Manoeuvring Basins[5,21].

Name and Location of Basin	Dimensions
CANADA	
B.C. Research, Vancouver[20].	30 m x 30 m x 2.4 m
National Research Council, Marine Dynamics and Ship Laboratory, Ottowa.	122 m x 61 m x 3 m
Veracruz Ship Hydrodynamics Institute, Ottowa[4].	100 m x 30 m x 5 m Joined end to end with 100 m x 30 m x 1 m
FINLAND	
Ship hydrodynamics laboratory, Helsinki University of Technology, Otaniemi[22].	40 m x 40 m x 3 m (max)
FRANCE	
Bassin D'Essais Des Carenes De Paris.	65 m diameter, 5 m deep (Rotating arm) 30 m x 7 m x 2.4 m
GERMANY WEST	
Versuchsanstalt Fur Binnenschiffbau, Duisburg.	25 m x 25 m x 1.1 m
JAPAN	
Dept. of Naval Architecture, Kyushu University, Fukuoka.	25 m x 25 m x 1.8 m
Ship Research Institute, Shinkawa, Mitaka, Tokyo.	80 m x 80 m x 4.5 m (60 m diameter, 4.5 m depth)
Seakeeping Laboratory, University of Tokyo, Chiba[24].	50 m x 30 m x 2.5 m
Yokohama Research Institute, Ishikawajima-Harima Heavy Industries. Isogo, Yokohama[25].	70 m x 30 m x 3 m
Nagasaki Technical Institute, Mitsubishi Heavy Industries[19].	S-Basin, 160 m x 30 m x 3.5 m M-Basin, 60 m x 60 m x 2 m
Kyushu University, Hakozaki, Fukuoka.	28 m x 25 m x 1.8 m (with rotating arm)
Tokyo University of Mercantile Marine, Fukagawa, Tokyo.	5.5 m x 4 m x 0.5 m

Name and Location of Basin	Dimensions
NETHERLANDS Netherlands Ship Model Basin, Wageningen [26].	100 m x 25 m x 2.5 m 60 m x 40 m x 1.2 m
POLAND Technical University of Gdansk - Wrzeszcz.	50 m x 50 m x 0.5 m
SWEDEN Statens Skeppsprovningsanstalt, Goteborg.	24.5 m x 24.5 m (Rotating arm)
UNITED KINGDOM Ship Division, National Physical Laboratory, Feltham.	30.5 m x 30.5 x 2.4 m deep
Admiralty Experiment Works, Haslar, Gosport, Hants [13].	122 m x 61 m x 4.6 m deep
Experimental and Electronic Laboratories, British Hovercraft Co. Ltd., Osborne.	55 m x 14.6 m x 0.6 m 15.2 m x 3.7 m x 1.7 m (Roll stability and damping basin)
UNITED STATES OF AMERICA Davidson Laboratory, Stevens Institute of Technology, Hoboken, New Jersey.	23 m x 23 m x 1.4 m
Harold E. Saunders Manoeuvring and Seakeeping Facilities, David Taylor Naval Ship Research and Development Centre, Bathesda, Maryland.	110 m x 73 m x 6.1 m 79 m diameter, x 6.4 m deep (Rotating arm)
Offshore Technology Corporation, Escondido, California.	120 m x 48 m x 15 m
Dept. of Naval Architecture, Ship Hydrodynamics Lab., University of Michigan, Ann Arbor, Michigan.	30.5 m x 24.4 m x 1.8 m
U.S.S.R. Kryloff Shipbuilding and Research Institute, Leningrad [12].	70 m diameter, 6.4 m deep (Rotating arm) 110 m x 70 m x 5.5 m
YUGOSLAVIA Brodarski Institute, Zagreb.	3 m diameter, 2.5 m deep (Rotating arm)

APPENDIX 3. Water tunnels and water channels[5,17,27,28].

Abbreviations: C=closed, FS=free surface, H=horizontal, R=recirculating, V=vertical

Place and tunnel	Circuit type and plane	Working section					Max. power (kW)	Pressure control
		Type of throat	Cross section (mxm)	Length (m)	Max. velocity (m/s)	Max. pressure (kg/cm^2)		
ARAB REPUBLIC OF EGYPT								
Alexandria Uni., Alexandria.	C,V		0.5x0.5	2.2	11	2 atm.	52	yes
ARGENTINA								
Buenos Aires Uni.	C,R,V		0.3x0.3	1.27	9	2 atm.	11	yes
AUSTRALIA See table 1.								
BRAZIL								
Inst. De. Pesquigas Tech., Sao Paulo.	C,R,V		0.5x0.5	2.2	10	2 atm.	52	yes
CANADA								
N.R.C., Marine Dyn. and Ship Lab., Ottawa.	C,R,V	C	0.5x0.5	2.2	13	2 atm.	56	yes
FRANCE								
Bassin D'Essais De Carenes, Paris	C,R,V R,FS	C FS FS	0.9 dia 0.6x0.6 or 0.6x0.15 1.0x1.0	1.0 3.6	18 6 18 6.3	2.0 2 atm.	560 900	yes yes
Sorgreah, Grenoble.	Turbine testing V	C	0.5 dia	1.5	5.5	3	170	yes
	Turbine testing V	C	0.55 dia.	2.5	5	3	450	yes
	C,R,V	C	0.5 dia or 0.6x0.7	10	9.5	3	450	yes

APPENDIX 3 (CONTINUED)

Place and tunnel	Circuit type and plane	Working section					Max. power (kW)	Pressure control
		Type of throat	Cross section (mxm)	Length (m)	Max. velocity (m/s)	Max. pressure (kg/cm^2)		
	C,R,V	C	0.25 dia. or 0.2x0.3	4	6	2	110	yes
	F S,V	C	0.5 dia. or 0.6x0.7	15	5	2.5	200	yes
CEAT, Poitiers	Blow down, horiz.	FS	0.25 d		70	10 bar abs	Comp. air, 25 bar	no
FINLAND								
Helsinki Univ. of Tech.,[22] Helsinki	R	FS	1.5x1.0	6.5	2	1 atm	33	no
	R	FS	0.4x0.29	1.9				
GERMANY EAST								
Rostock, K21	C,R,V		0.3x0.3	1.1	9	2 atm	14	yes
Inst. fur Schiffbau, Potsdam - Marquardt	C,V		0.6x0.6 or 0.85x 0.85	2.60	12 or 6	2 atm	100	yes
GERMANY WEST								
Tech. Univ., Darmstardt	C,R,V	C	0.08x 0.13	0.47	25	15	60	yes
HSVA, Hamburg	C,R,V	C	0.75 dia	2.25	19.5	2.5 atm	350	yes
	C,R,V	C	0.4x0.4	1.5	5.3	1 atm	175	yes
	C,R,V	C	0.57x 0.57	2.2	8.5	1 atm	52	yes
Staatl. Ing. Schule, Kiel	C,R,V		0.3x0.3	1.27	10	2.0	11	yes
	FS,R		0.7x1.5	6	2.6	1.0	7.8	no

APPENDIX 3 (CONTINUED)

Place and tunnel	Circuit type and plane	Working section					Max. power (kW)	Pressure control
		Type of throat	Cross section (mxm)	Length (m)	Max. velocity (m/s)	Max. pressure (kg/cm^2)		
MANY WEST (CONTD.)								
chnical Uni. unich	C,R,V or FS,R,V	C or FS	0.3x0.3 0.48x0.28	1.8	16 7	2 atm 1 atm	90	yes
	C,R,H	C	0.4 dia	2.0	6	5 atm	90	yes
ech. Uni., erlin	FS,R,V	FS	0.6x(0.3-0.6)	3.8	14-18	1 atm	600	yes
	FS,R,V	FS	0.12x (0.06-0.12)	0.8	11-14	1 atm	25	yes
ersuchsans- it fur serbau und chiffbau, erlin	C,R,V	C	0.42x 0.42 or 0.3x0.3	1.4	5.8 10.8		11	yes
	C,R,V[29]	FS	5.0x3.0 or 2.0x1.0	10	5 or 12		4500	yes
	R,V	FS	1.8x1.2	7	6		335	
TALY								
EIMM, Rome	C,R,V	C	0.6x0.6	2.6	14	2 atm	100	yes
st. Di. Arch. Navale, ni. Di Genova	Open, H,R	FS	1.10x .10	7.8	1.2	1 atm	35	no
APAN								
okyo Uni., ongo, Tokyo	C,R,H		0.03 dia	0.12	80	35	68	yes
	H,R	FS	1.5x1.4	5.5	2.0		30	
okyo Uni. ercantile arine, Tokyo	H,R	FS	1.2x0.75	3.0	2.0		19	

APPENDIX 3 (CONTINUED)

Place and Tunnel	Circuit type and plane	Working section					Max. power (kW)	Pressure control
		Type of throat	Cross section (mxm)	Length (m)	Max. velocity (m/s)	Max. pressure (kg/cm^2)		
Ship Research Inst., Mitaka, Tokyo	C,R,V	C	0.5 dia	1.15	9	1 atm	40	yes
	C,R,V	C	0.75 dia or 2.0x0.9	2.25	19	2	355	yes
	R,V	FS	0.6x0.5	2.4	2.0		4	
Toshima - Ku, Mejiro, Tokyo	V		0.6x0.6	2.6	12	2	97	yes
IHI, Yokohama	C,R,V	C	0.6 dia	1.07	7	1 atm	56	yes
Mitsubishi Exp. Tank, Nagasaki	C,R,V	C	0.5x0.5	2.2	11	1.2 atm	51	yes
Inst. High Speed Mech., Tohoku Univ., Sendai	C,R,V	Slotted wall	0.07x 0.19		15	3 atm	11	yes
	C,R,V	Slotted wall	0.1x 0.34		12	1 atm	56	
	C,R,V	Slotted wall	0.1x0.3		33	15 atm	520	yes
	C,R,V	Slotted wall	0.2x1.2		13	4.5 atm	370	yes
Col. of Nav. Arch. of Nagasaki	R,V	FS	0.8x0.6	2.4	2.0		7.5	
Def. Academy, Yokosuka	R,H	FS	1.2x1.2	6	1.8		30	
Fishing Boat Lab., Tokyo	R,H	FS	1.2x0.7	3.3	1.0		4	
Hiroshima Univ., Hiroshima	R,H	FS	1.2x0.8	3	1.0		2.2	
Hitachi Ship-building Co., Osaka	R,H	FS	1.2x1.2	6.1	1.5		30	
	C,R,V	C	0.15 d	1.5	30	25 atm	110	yes

Place and tunnel	Circuit type and plane	Working section					Max. power (kW)	Pressure control
		Type of throat	Cross section (mxm)	Length (m)	Max. velocity (m/s)	Max. pressure (kg/cm^2)		
JAPAN (CONTD.)								
Ibaraki Uni., Ibaraki	R,V	FS	0.6x0.45	1.8	1.2		4	
Kagoshima Uni., Kagoshima	R,H	FS	2.0x1.0	7.0	1.0		7.5	
Kowasaki Heavy Indus., Akashi, Hyugo	R,H	FS	2.0x1.3	6.0	2.5		75	
Mitsui Ship-building and Eng., Ichihara, Ciba	R,V	FS	2.0x1.2	5.5	3.0		75	
Niigata Ship-yard, Niigata	R,H	FS	1.5x1.2	6.5	2.0		37	
Nippon Kokan, Tsurumi, Yokohama	R,H	FS	1.2x0.8	3.7	1.7		22	
Sasebo Heavy Indus., Sasebo	R,H	FS	1.5x1.5	4.0	1.0		7.5	
Uni. of Osaka, Osaka	H,R	FS	1.5x1.0	6.5	3.0		37	
NETHERLANDS								
Univ. of Tech., Delft	R,V,C	C	0.3x0.1	1	9	1 atm	15	yes
	R,V,C	C	0.3x0.15	1	11	1 atm	15	yes
	R,V	FS	0.6x0.3	3	1.2	1 atm	15	yes
NSMB, Wageningen	C,R,V	C	0.9 Oct	4	11	1.8 atm	300	yes
	C,R,V	Slotted	0.4 dia	0.8	7	1.5 atm	22	yes
	C,R,V	C	0.24 dia.	0.3	7	1.5 atm	65	yes
	C,R,V	C	0.04 dia.	0.06	65	35 atm	58	yes

Place and tunnel	Circuit type and plane	Working section					Max. power (kW)	Pressure control
		Type of throat	Cross section (mxm)	Length (m)	Max. velocity (m/s)	Max. pressure (kg/cm^2)		
NETHERLANDS (CONTD.)								
Apeldcorn	C,R,V	C	3.1x3.1	6	20	8	1400	yes
NORWAY								
Norwegian Ship Model Exp. Tank, Univ. of Trondheim	C,R,V	C,O, or Slotted	0.36 dia	0.53	6.5	1 atm	9	yes
	C,R,V	C	1.2 dia	2.08	18	6.2	1250	yes
POLAND								
Ship Res. Inst., Univ. of Gdansk	R,H	FS	1.0x1.0	5.0	1.5		10	
SPAIN								
Canal De Experiencias Hidrodinamicas, Madrid	C,R,V	C	0.9x0.9	4.7	11.0	1.6	225	yes
SWEDEN								
Swedish State Shipbuilding Exp. Tank, Goteborg	C,R,V	C	0.5x0.5 or 0.7x0.7	2.2 or 2.4	11 6	2 atm	53	yes
	C,R,V,	C	1.0 dia or 1.5x2.6	2.5 or 9.6	23 7	6 atm 2 atm	74	yes
KMW, Kristinehamn	C,R,V	C	0.8x0.8	1.0	14	1 atm	250	yes
	R,V	FS	0.8x1.6	4	12	1 atm	970	yes
	C,R,V	C	0.8x0.8	2.5	15	3 atm	250	yes

Place and tunnel	Circuit type and plane	Working section					Max. power (kW)	Pressure control
		Type of throat	Cross section (mxm)	Length (m)	Max. velocity (m/s)	Max. pressure (kg/cm^2)		
TURKEY								
Shipbuilding Res. Inst., Tech. Univ., Istanbul			0.3x0.3	1.29	9	2	11	yes
			0.63x 0.35	2.3	3.8	2	11	yes
UNITED KINGDOM								
AEW, Haslar	C,R,V	C	0.61x 0.61	0.58	12.2	1.1	110	yes
	C,R,V	C	2.4x1.2	5.33	8	1.22	300	yes
	R,V	FS	1.4x 0.84	5.0	6.5	1.07	75	yes
ARL, Teddington	C,R,V	C or slotted	0.3 dia	1.52	25 or 21	3.2	225	yes
	C,R,V	Slotted	0.76 dia	4.42	19	3.2	630	yes
Nat. Maritime Inst., Feltham	C,R,V	C or slotted	0.46x 0.46	1.01	8.5	1.5 atm	60	yes
	C,R,V	C	1.12 dia	2.23	17	6 atm	750	yes
	R,H	FS	3.7x2.4	15	3.0		1800	
Loughborrough	R,H	C or FS	0.30x 0.12	1.2	6	Atm	5.6	yes
Leeds	C,R,V	FS	0.36x 0.36	2.44	6.1	2 atm	29	yes
Univ. of Newcastle, Newcastle	C,R,V	C	1.22x 0.81	3.66	7.3	1 atm	300	yes
[illegible]C, East Cowes	C,R,V	C	0.25x 0.41	1.14	5.2	1 atm	37	no

APPENDIX 3 (CONTINUED)

Place and tunnel	Circuit type and plane	Working section					Max. power (kW)	Pressure control
		Type of throat	Cross section (mxm)	Length (m)	Max. velocity (m/s)	Max. pressure (kg/cm^2)		
UNITED KINGDOM (CONTD.)								
Uni. of Oxford, Oxford	C,R,V	Any	0.18x 0.23	1.07	12.5	6 atm	56	yes
Turbine Test Res. Centre, East Kilbride	open or closed		0.38x 0.05	0.61	36.5	500 atm ?	530	yes
Uni. of Liverpool, Liverpool	C,R,V	C or FS	1.4x 0.84	5	6.1	1 atm	75	yes
Vosper, Portsmouth	C,R,V	C	0.5x0.5	2.2	12.5	2.11	57	yes
Exp. and Elec. Labs., British Hovercraft Co., Osborne	C,R,V	C or FS	0.25x 0.33	5.2				
Kings Col., Nav. Arch. Dept., London	C	C	1.01x 0.81	3.66	7.3		225	yes
UNITED STATES OF AMERICA								
Webb Inst. of Naval Arch., Glen Cove, N.Y.	R	FS	0.9x 0.45	2.8	2.2		4	yes
St. Anthony Falls Hydraulics Lab., Uni. of Minneapolis, Minnesota	R	FS	0.19x 0.19	1.2	29	2 atm	110	yes
	Non. R,V	Free jet	0.25 dia	1.0	15	1 atm	Gravity	yes
	C,R	Closed or slotted or open jet	0.15 dia	0.08 to 0.76	16.5	2.28	11	yes
	R,V		1.07 dia	4.57		5.4	110	yes
		(Dimension of outer pressure shell, linear conduct of shape and size needed)						

Place and tunnel	Circuit type and plane	Working section					Max. power (kW)	Pressure control
		Type of throat	Cross section (mxm)	Length (m)	Max. velocity (m/s)	Max. pressure (kg/cm^2)		
UNITED STATES OF AMERICA (CONTD.)								
		FS	0.9x1.5	3.0	1.5		Gravity	
		FS	0.46x 0.3	15.0	14		Gravity	
		FS	0.76x 1.0	12.2	3.0		Gravity	
		FS	0.51x 0.71	9.1	3.0		Gravity	
		FS	0.30x 0.60	9.1	3.0		Gravity	
		FS	0.30x 0.60	9.1	3.0		Gravity	
DTNSRDC, Carderock, Maryland	R,V	FS	6.7x2.7	18	5.2			
	C,R,V	Open jet	0.15x 0.30	0.64	6.5	1 atm	11	yes
	C,R,V	Open jet or closed	0.61 dia. or 0.69 dia.	0.53 or 1.22	17	2.44	560	yes
	C,R,V	Open jet or closed	0.91 dia.	1.07 or 1.83	25.7	4.22	2600	yes
California Inst. of Tech., Pasadena	C,R,V	C	0.35 dia. or 0.15x 0.76	1.24 or 1.27	32 or 24	7.0	370	yes
	R,V	FS	0.51x 0.51	2.5	8.4	1 atm	860	yes
Stevens Inst. Hoboken, N.J.	C,R,V	FS	0.30x 0.18	1.8	6	1 atm	7.5	yes

Place and tunnel	Circuit type and plane	Working section					Max. power (kW)	Pressure control
		Type of throat	Cross section (mxm)	Length (m)	Max. velocity (m/s)	Max. pressure (kg/cm^2)		
UNITED STATES OF AMERICA (CONTD.)								
Hydronautics Inc., Laurel, Maryland	R,V	FS	0.61x 0.61 or 0.61x 0.15	3.66	6.1 or 18.3	atm	750	yes
	C,R,V	C	0.18 dia	0.97	23	15.1	110	yes
	C,R,V	C	0.05x 0.08	0.46	49	11.6	75	yes
Oceanics Inc., Plain view, N.Y.	C,R,V	C	0.5x0.5 or 0.71x 0.71	2.2 or 3.34	11.6 or 6.7	2 atm	52	yes
Uni. of Michigan, Ann Arbor	C,R,V		Variable 0.1 dia max.	0.61	61	4 atm	45	yes
State Coll. Pennsy. Ord. Res. Lab.	C,R,V	C	1.22 dia	4.3	24.4	4 atm	1500	yes
	C,R,V,	C	0.3 dia or 0.51 x 1.08	0.77	21	4 atm	110	yes
	C,R,V	C	0.038 dia	0.086	110	80 atm	110	yes
M.I.T., Cambridge	C,R,V	Open jet	0.51 dia	0.56	10	2 atm	56	
Navy, Pasadena	C,R,V	Semi-open jet	0.3 dia	0.46	12.2		75	yes
U.S.S.R.								
Kryloff Ship-building and Res. Inst., Leningrad	C,R,V	C	0.5x0.5	1.0	10	1 atm	77	yes
	C,R,V	C	0.66x 0.66	1.12	13	1 atm	188	yes
	C,R,V	C	1.3x1.3	5.1	15	3 atm	1860	yes
	C,R,V	C	0.4 dia	1.0	9	1 atm	39	yes
	C,R,V	C	0.085 dia	0.4	43	2 atm	56	yes

Place and tunnel	Circuit type and plane	Working section					Max. power (kW)	Pressure control
		Type of throat	Cross section (mxm)	Length (m)	Max. velocity (m/s)	Max. pressure (kg/cm^2)		
YOGOSLAVIA Brodarski Inst., Zagreb	C,R,V	C	1.0x1.0	3.6	11.3	2 atm	225	no
	C,R,V	C	0.5x0.5	2.4	8.0	2 atm	27	no

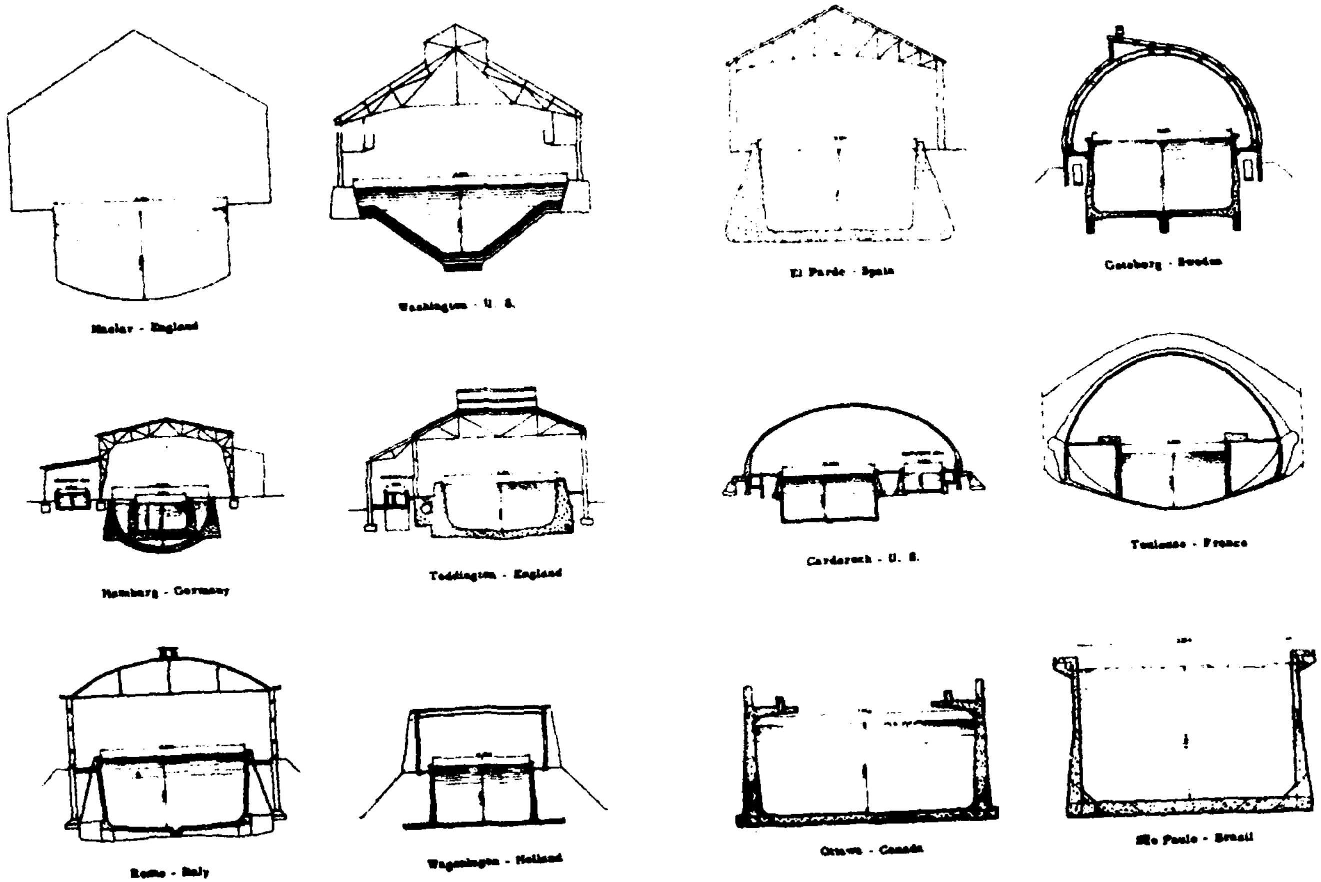

FIG.1 TOWING - TANK FACILITIES IN CROSS SECTION (ref.15)

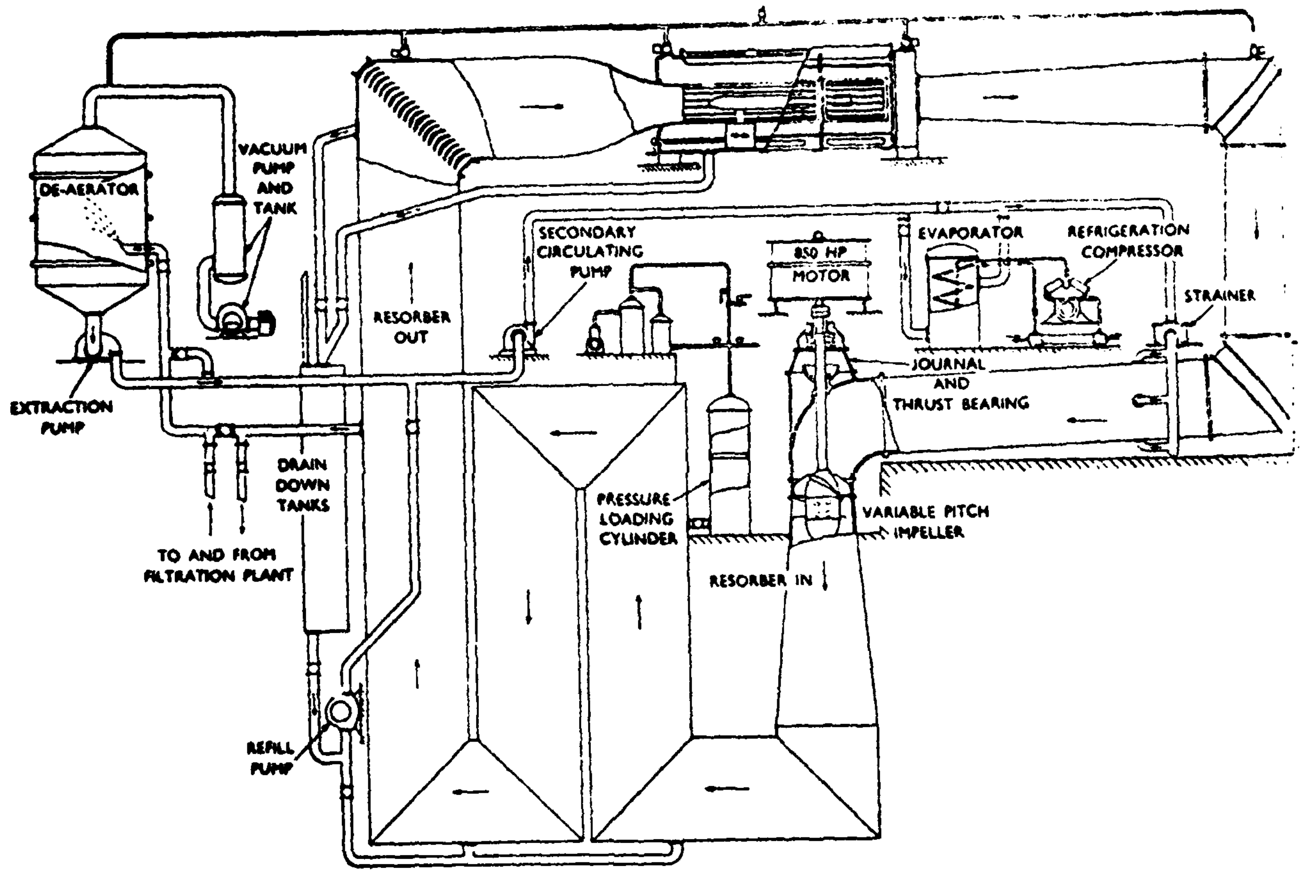

FIG.2 ADMIRALTY RESEARCH LABORATORY 30 - INCH WATER TUNNEL AND ANCILLARY PLANT (ref.16)

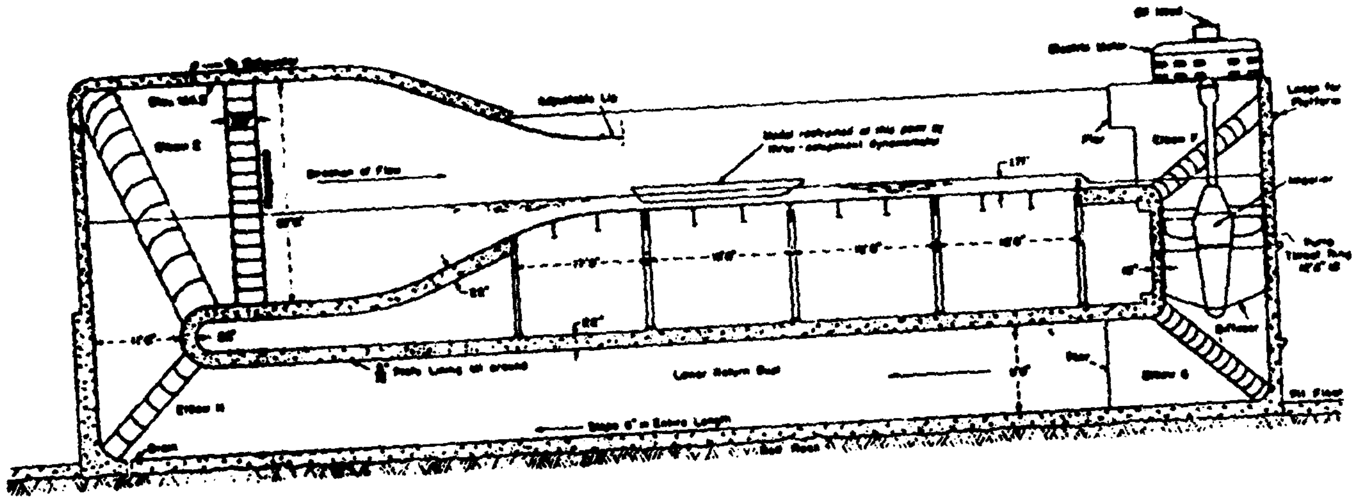

FIG.3 VERTICAL LONGITUDINAL SECTION THROUGH THE CIRCULATING WATER CHANNELL AT THE DAVID TAYLOR NAVAL SHIP RESEARCH AND DEVELOPING CENTRE (ref. 14)

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